Proceedings of the 11th ICPMG 2026
11th International Conference on Physical Modelling in Geotechnics
8-12 June 2026, Zurich, Switzerland

Submarine landslides against a deformable cable: a tilting table centrifuge model

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ABSTRACT: The offshore energy transition employs an extensive network of sea cables as part of its support infrastructure. Sea cables are frequently laid directly on the seabed or with minimal burial depth, leaving them exposed to geohazards or anthropic interactions. In this work we study the interaction of an analogue system of a submarine landslide and a sea cable in a plane-strain configuration. This configuration is explored in a tilting table setup, allowing the immersed grains to push a spring-like cylindrical obstacle. As a result of tilting, multiple collapse events are observed resulting in two main interaction mechanisms: one where the cable displacement occurs by either the accumulation of soil behind the cable, or another where grains over- and under-flow around the cable. The combination of cable displacement and the grains displacement field allows tracking the soil-cable interaction. This interaction is simplified into a dimensionless force ratio, similar to Rankine's lateral earth pressure approach, capturing the advantage of considering the cable displacement when compared to the current practice of assuming it as a bottom-fixed rigid body. The insights from both models provide a comprehensive overview on the governing interactions on a deformable cable, paving the path for its implementation by the design practice and potential development of mitigation measures for this type of critical infrastructure.

Offshore energy production and subsea telecommunications rely on extensive networks of linear submarine infrastructures such as pipelines and cables. Sea cables are frequently laid directly on the seabed or with minimal burial depth, leaving them exposed to geohazards or anthropic interactions. These interactions pose a risk of them being snapped, deformed, or broken, resulting in costly operations and compromising their energy distribution (Pasqua et al., 2025). The relevance of such hazards to the engineering practice is underscored by design frameworks such as the DNV-RP-F109 and DNVGL-RP-F114, which provide guidance on both on-bottom stability and pipeline-soil interaction. However, these are challenged when the impacted object undergoes significant displacement.

In this work we study the interaction of an analogue system of a submarine landslide and a sea cable in a plane-strain configuration. The physical model considers the cable as an element able to move continuously in response to external loads, with this motion resisted by its own elongation capacity and lateral stiffness. This is a challenging problem to model experimentally, as realistic stress fields must be considered while accounting for the coupled motion of the seabed material and the deformable structure. To achieve this, tests are performed at the 1.2 m radius centrifuge at TU Delft (Allersma, 1994), under an effective acceleration of $Ng = 20g$. For this scaling, a 0.56 m diameter cable in the prototype can be scaled to a 28 mm diameter in the model. Furthermore, its model axial stiffness $\zeta_m = 2EA/L$ would be N times smaller than in the prototype, with E, A and L as the cable Young modulus, cross-section area and span length, respectively. This scaling enables the investigation of complex soil–structure interaction processes in a small container under controlled boundary conditions.

The experimental setup adapts the centrifuge tilting tank presented in Zhang and Askarinejad (2021). The tilting platform holds a prismatic strongbox of 400 mm long, 160 mm wide, and 300 mm high. Details of the apparatus are in Fig. 1. Inside the strongbox, a cylindrical rigid cable hangs from two linear bearings connected to a linear spring of axial stiffness ζ. The strongbox is filled with 3 mm glass beads (ρ=2500kg/m^3, φ=30°), as an analogue to soil, and water. The fully submerged model is tilted at angles between 0° and 25°, at a maximum rate of 2°/s. The cable consists of a Teflon rod, 28 mm diameter

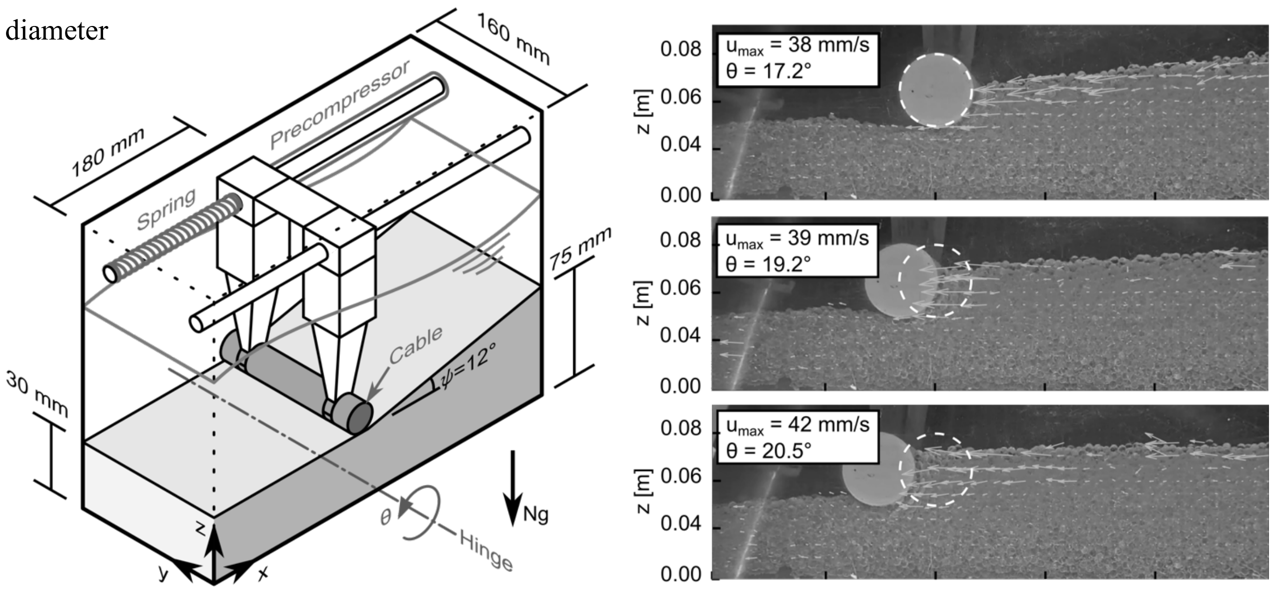

Figure 1. Experimental setup for investigating the interaction between a submarine landslide and a long submarine infrastructure (right) and snapshots and velocity field from a collapse sequence that displaces the cable (left).

and 158 mm long, connected through 3D-printed I-beams to two linear ball bearings. The linear bearings are connected and guided by two 16 mm steel shafts at the top of the strongbox. A linear compression spring is mounted around one of the shafts between the linear bearing and the strongbox wall. During tilting, the cable self-weight has a non-zero downslope force component, which could result in a premature motion before slope collapse. To prevent this, the spring is pre-compressed so that the elastic force is balanced by the immersed self-weight until the slope inclination reaches the target slide angle. A network camera (AXIS P1245) is fixed to the strongbox, recording at 25 fps with a resolution of 1280 by 720 pixels. Simultaneously, two string potentiometers (WPS-150-MK30-P25) connects the linear bearings to the strong box wall, allowing the measurement of the cable position and its displacement.

Just before impact, the slope is stable, and the cable is stationary with all forces balanced, Fig. 1. Once the slope collapse sequence begins, a shallow instability forms, impacting and accumulating behind the cable. This leads to the cable and beads movement downslope, compressing the spring until reaching a new equilibrium state. As tilting continues, the accumulated beads behind the cable can become unstable again, initiating another collapse sequence.

The experiments reproduced a simplified midspan spring model, allowing controlled variation of stiffness and measurement of the resulting displacement and force evolution. It is found that the cable flexibility strongly influences the sequence of events during impact. The experimental evidence presented here offers a basis for expanding current engineering practice and in standards to include deformable structures. The observations gained from this model would allow incorporating stiffness-dependent load–displacement curves for immersed flexible elements.

ACKNOWLEDGEMENTS

This work was financially supported by the Engineering and Physical Sciences Research Council (EPSRC), under grant number EP/Y00132X/1, titled "Submarine mass movements and their interaction with critical offshore infrastructure". We also extend our gratitude to our industry partner Geowynd, to L. Zuccarino, O. Zanoli, and R. Malgesini, and the R. Klassen at TU Delft for his support during the execution of experiments.

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